Stock Assessment and Restoration of the Afognak Lake Sockeye Salmon Run

Annual Report for Study 04-412

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Abstract

Afognak Lake sockeye salmon *Oncorhynchus nerka* runs declined substantially in 2001 and subsequent escapements from 2002-2004 have been well below the escapement goal. Responding to concerns from local subsistence users, the Alaska Department of Fish and Game began investigations of the lake's rearing environment. With successful completion of a one-year mark-recapture feasibility study to estimate smolt abundance in 2003, a three-year study (2004-2006) to continue the smolt abundance estimates and assess rearing and spawning habitats was funded.

During 2004, 67,528 sockeye salmon smolt were captured using a Canadian fan trap operated from 11 May to 3 July. Using mark-recapture techniques, we estimated that 430,004 sockeye salmon smolt (95% C.I. 371,905 - 488,104) emigrated from Afognak Lake. The population was composed of 387,584 age-1. and 42,420 age-2. smolt. Age-1. smolt had a mean weight of 3.6 g, a mean length of 75.7 mm, and a mean condition factor of 0.80. Age-2. smolt had a mean weight of 3.6 g, a mean length of 78.7 mm, and a mean condition factor of 0.74.

Five limnology surveys were conducted at two stations in Afognak Lake from May to September, 2004. Seasonal water chemistry and nutrients concentrations were consistent with historical data collected from Afognak Lake. Afognak Lake is considered phosphorus limited. Seasonal zooplankton density averaged 104,291 animals per m^{-2}, and cladocerans comprised 54.6% of the zooplankton sampled. The cladoceran *Bosmina* was the most abundant zooplankter, while *Epischura* was the most abundant copepod.

Rearing conditions within Afognak Lake appear to be stable or improving since lake's water chemistry and nutrients were similar to historic levels and zooplankton abundance did not suggest overgrazing. Favorable rearing conditions were also reflected in the relatively high condition factor of the smolt (>0.70) that enabled most of them to emigrate at age-1.

Key words: Afognak Lake, Afognak Island, age, emigration, escapement, Kodiak Island, *Oncorhynchus nerka*, smolt, sockeye salmon, subsistence harvest, trap, zooplankton.

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INTRODUCTION

Afognak Lake sockeye salmon *Oncorhynchus nerka* runs declined substantially in 2001, and subsequent escapements during 2002-2004 were well below the sustainable escapement goal (SEG) range of 40,000 to 60,000 fish (Wadle 2001; Honnold and Schrof 2004). As a result of these poor returns, the commercial sockeye salmon fishery in Afognak Bay has been closed since 2001 (Table 1). Sport fishing restrictions were also implemented in 2001, and in-season closures and reduced bag limits have occurred each year since that time. In conjunction with commercial and sport fishing closures, State and Federal managers closed subsistence fishing in early June during the 2002 season, and in-season closures have occurred each year since that time. The 2002 subsistence fishing closure was unprecedented in the Kodiak Management Area (KMA) and caused subsistence fishing effort to shift to other systems. Subsistence salmon fishing has been allowed in Afognak Bay for pink *O. gorbuscha* and coho *O. kisutch* salmon starting 1 August each year.

The Afognak Lake sockeye salmon run has historically provided for the largest subsistence salmon fishery on Afognak Island and the second largest in the Kodiak Archipelago (Honnold and Schrof 2004). Local villagers from Port Lions and Ouzinkie as well as Kodiak area residents harvest sockeye salmon returning to Afognak Lake. The subsistence fishery occurs entirely within the Alaska Maritime National Wildlife Refuge. Subsistence harvests in Afognak Bay have ranged from 1,279 (2002) to 12,412 (1997) sockeye salmon during 1990-2002 (Table 1). During that same time period, subsistence harvest effort ranged from 120 (1998) to 376 (1996) participants. The smallest documented subsistence harvests occurred during 2003 (604 sockeye salmon) and 2004 (567) when managers determined the escapement goal would not be achieved and closed the subsistence fishery early in each season.

The possibility of future subsistence closures in Afognak Bay were of great concern to local subsistence users, who are represented by the Kodiak-Aleutian Islands Regional Advisory Council, Kodiak Fish and Game Advisory Committee, and Kodiak Tribal Council. They contended that a continued closure of this system would make it more difficult for local residents to harvest sockeye salmon and would shift fishing effort to the Buskin River and small sockeye salmon runs in the area. The Regional Advisory Council, Kodiak Advisory Committee, and Kodiak Tribal Council informed the Alaska Department of Fish and Game (ADF&G) and U.S. Fish and Wildlife Service (FWS) that the Afognak Lake sockeye salmon run failure constituted an emergency situation for their constituents. In response to this problem, the ADF&G received funding through the Office of Subsistence Management (OSM), Fisheries Resource Monitoring Program to determine the feasibility of estimating sockeye salmon smolt production from Afognak Lake. This study showed that sockeye salmon smolt could be effectively trapped in Afognak River and their abundance reliably estimated using mark-recapture techniques (Honnold and Schrof 2004). Smolt abundance studies are important in that they assess the relative success of the entire freshwater rearing stage ranging from when the eggs were deposited in the gravel to when the subsequent smolt leave the freshwater.

In addition to smolt data, ADF&G felt it was important to determine the smolt production capacity of Afognak Lake. Sockeye salmon mortality rates are usually greatest during the freshwater life history stage (Burgner 1991), and the ADF&G and Kodiak Regional Aquaculture

Association had fertilized (1990-2000) and stocked juveniles into (1992, 1994, 1996-1998) Afognak Lake to restore the sockeye salmon run. As part of the evaluation process, limnological data were collected three years prior to, during, and three years after rehabilitation activities. However, limnology data collection would end after 2003, unless the ADF&G obtained additional funding for the continued collection of limnological data (phosphorus-nitrogen, chlorophyll *a*, and zooplankton) to determine the factors that would limit sockeye salmon production during freshwater rearing. Based on the findings from the 2003 feasibility study, OSM provided funding for a three-year study (2004-2006) that would continue smolt assessment work and examine rearing and spawning potential of Afognak Lake. This report provides results from the first year of this study.

Objectives of the Project in 2004

The project objectives were to 1) estimate the number of sockeye salmon smolt by age emigrating from Afognak Lake; 2) determine the average weight, length, and condition factor of the smolt; 3) estimate the timing by age class of the sockeye salmon smolt emigration from Afognak Lake and; 4) evaluate the water chemistry, nutrient status, and plankton production of Afognak Lake.

A fifth objective to measure the useable spawning habitat available for sockeye salmon in the Afognak Lake drainage was postponed until 2005.

Background

Federal and State agencies have operated weirs to count salmon on various systems within KMA since the early 1920s (Kuriscak 2004). A weir has been operated on the Afognak River annually since 1978. Weir counts along with catch data (commercial, subsistence, and sport) have provided managers with an estimate of adult sockeye salmon production, but little information on juvenile production has been collected.

Juvenile production studies have been conducted in conjunction with limnological investigations at a number of sockeye salmon systems in the Kodiak archipelago, although only a limited information on juvenile production has been collected for Afognak Lake (White et al. 1990; Schrof et al. 2000). Most projects on juvenile sockeye salmon production in Kodiak area systems have provided data for evaluating possible effects of overescapement (Akalura, Frazer and Red Lakes; Kyle et al. 1988; Barrett et al. 1993a,b; Coggins 1997; Coggins and Sagalkin 1999; Sagalkin 1999), or were part of lake rehabilitation projects (Malina and Karluk Lakes; Kyle and Honnold 1991; Schrof and Honnold 2003). These studies estimated smolt abundance and size by age using trapping and mark-recapture techniques. Currently, juvenile production data are being collected from six sockeye salmon systems in the Kodiak archipelago and on the Alaska Peninsula (Schrof and Honnold 2003; ADF&G 2004). Sagalkin and Honnold (2003) assessed potential sources of error in mark-recapture estimates from smolt enumeration projects, including mortality caused by marking, handling, and trapping, and bias associated with smolt size and behavior. Effects of these sources of error were judged to be negligible.

Freshwater production of sockeye salmon has been examined within a variety of systems within Alaska by enumerating sockeye salmon smolt emigrating from lakes and measuring primary and secondary production in these lakes (Koenings et al. 1987). Primary production within lakes is driven by both physical conditions, such as temperature and dissolved oxygen, which affect nutrient cycling (Schlesinger 1991), and nutrient concentrations, especially phosphorous and nitrogen, which are required for photosynthesis (Spalinger and Bouwens 2003). Chlorophyll *a* levels are used as indicators of phytoplankton standing crop, which provide food for zooplankton that in turn are eaten by juvenile sockeye salmon. Zooplankton abundance, individual size, and species composition can be regulated from the bottom-up by phytoplankton availability (Stockner and MacIsaac 1996), or by top-down pressures such as grazing by juvenile sockeye salmon (Kyle 1992). Zooplankton population attributes are sometimes used by the ADF&G to determine juvenile stocking rates and juvenile salmon rearing capacity (Kyle et al. 1990; Honnold 1997; Honnold and Schrof 2001).

Finally, the amount and quality of available spawning habitat also determines sockeye salmon freshwater production. Little information is available on spawning habitat within the Afognak Lake system. White et al. (1990) reported unpublished results of a spawning habitat survey conducted sometime during the 1970s at Afognak Lake, but the methods used were not recorded. Current information on spawning habitat area and quality is needed to fully understand the productivity potential of the Afognak Lake system (Honnold and Edmundson 1993; Willette et al. 1995).

Description of Study Area

The Afognak Lake system is located on the southeast side of Afognak Island approximately 50 km northwest of the city of Kodiak (Figure 1). Afognak Native Corporation owns the land surrounding the system, but most subsistence fishing occurs in Afognak Bay, which is part of the Alaska Maritime National Wildlife Refuge. Afognak Lake (58^{o} 07' N, 152^{o} 55' W) lies about 21 m above sea level, is 8.8 km long, 0.8 km wide at its widest point, and has a surface area of 5.3 km^{2} (White et al. 1990; Schrof et al. 2000). The lake has a mean depth of 8.6 m, a maximum depth of 23.0 m, and a lake-water residence time of 0.4 years (Figure 2). Runoff from Afognak Lake flows in an easterly direction via the 3.2 km Afognak River, which flows into Afognak Bay.

In addition to sockeye salmon, resident fish in the Afognak Lake drainage include pink salmon *O. gorbuscha*, coho salmon O. kisutch, rainbow trout (anadromous and non-anadromous) *O. mykiss*, Dolly Varden char *Salvelinus malma*, three spine stickleback *Gasterosteus aculeatus*, and coastrange sculpin *Cottus aleuticus* (White et al. 1990). Chinook *O. tshawytscha* and chum *O. keta* salmon have also been observed in the Afognak River on occasion, but have not established viable spawning populations (White et. al 1990).

METHODS

Smolt Assessment

Trap Deployment and Assembly

A Canadian fan trap (Ginetz 1977) was installed on 11 May, approximately 30 m upstream from the confluence of the Afognak River and Afognak Bay. The fan trap was positioned towards the middle of the river, where water velocity was sufficient to minimize smolt avoidance (Figure 3). A live box (1.2 m x 1.2 m x 0.5 m) was attached to the cod end of the trap, and the entire trapping device was suspended by cable attached to a come-along and secured to an aluminum pipe frame, which allowed trap position to be adjusted in response to water level fluctuations. Perforated (3.2 mm) aluminum sheeting (1.2 m x 2.4 m) supported by a rackmaster-type pipe frame was placed at the entrance of the trap in a “V” configuration to divert smolt into the live box. Trapping ceased, and the trap was removed from the river, when smolt abundance declined and the number captured was less than 100 per day for three consecutive days. Detailed methods for trap installation, operation, and maintenance are described by the ADF&G (2004).

Smolt Enumeration

Smolt were captured in the trapping system and held in the attached live box until they were counted. During the evening (2200 to 0800 hrs), the live box was checked every one to two hours, depending on smolt abundance. During the day (0801 to 2159 hours), the live box was checked every three to four hours. Smolt were removed from the live box with a dip net, counted, and either released downstream of the trap or transferred to an in-stream holding box for sampling and marking. Species identification was made by visual examination of external characteristics (Pollard et al. 1997). All data, including mortalities, were entered on a reporting form each time the trap was checked.

Age, Weight, and Length Sampling

A total of 200 sockeye salmon smolt were sampled each statistical week to obtain age, weight, and length (AWL) data. To reach the weekly total, daily samples of 40 sockeye salmon smolt were collected for five days within each statistical week. Smolt were collected throughout the night and held in the in-stream live box. The number of smolt collected each hour was proportional to emigration abundance. Forty smolt were randomly collected from those retained in the live box and sampled to obtain daily AWL data. After sampling, all smolt were released downstream from the trap.

Tricaine methanesulfonate (MS-222) was used to anesthetize smolt prior to sampling. Fork lengths (FL) were measured to the nearest 1 mm, and weights were recorded to the nearest 0.1 g. Scales were removed from the preferred area (INPFC 1963) and mounted on a microscope slide for age determination. After sampling, smolt were held in aerated water until they recovered from the anesthetic, and subsequently released downstream from the trap. Age was estimated from scales observed with a microfiche reader (EYECOM 3000) at 60X magnification, and recorded in European notation (Koo 1962).

Condition factor (Bagenal and Tesch 1978), a quantitative measure of "fatness," was determined for each smolt as:

$$K = \frac{W}{L^3} 10^5 \tag{1}$$

where,

K	=	smolt condition factor;
W	=	weight in g;
L	=	FL in mm.

Trap Efficiency and Population Estimates

Mark-recapture experiments were performed to measure smolt trap efficiency. Sockeye salmon smolt were marked (dyed) and released once per week and also when changes were made to the trapping system. Based on smolt studies at Akalura Lake (Coggins and Sagalkin 1999; Sagalkin and Honnold 2003), we attempted to achieve trap efficiencies between 15 to 20%. To achieve the desired trap efficiency and be within the relative abundance error (r) of 25% in estimating the total emigration, we needed to mark and release 300-500 smolt (Robson and Regier 1964; Carlson et al. 1998). To obtain the needed number of smolt to mark, we sometimes had to capture and hold smolt over a two-night period. When the desired number of smolt was collected, they were placed in an aerated 33-gallon water filled trashcan and transported in a trailer pulled by an all terrain vehicle, to the release site approximately 1,240 m upstream. At this site, smolt were transferred to a second holding box in the river and allowed to recover for 3 to 4 hours. In the holding box, smolt were then transferred, using a dip net, into a trashcan containing 1.9 g of Bismark Brown Y dye and 15 gallons of continuously oxygenated water. The smolt were held in the dye solution for 30 minutes, and then returned to the holding box to recover for at least 1 hour. Between 2100-2300 hrs, dyed smolt were counted and released across the width of the stream. Dyed smolt that displayed unusual behavior (labored breathing, flared gills, side swimming, etc.) were not released. All dyed smolt recaptured at the trap site were counted and assigned to a dye test period (hereafter referred to as a stratum).

Trap efficiency for each stratum (*h*) was calculated by dividing the total number of dyed smolt recaptured by the number of dyed smolt released within the stratum:

$$u = \frac{m_h}{M_h} \tag{2}$$

where,

u	=	exploitation rate of the smolt population;
M_h	=	number of marked smolt released in stratum *h;*
m_h	=	number of marked smolt recaptured in stratum *h*.

A modification of the stratified Peterson estimator (Carlson et al. 1998) was used to estimate the number of smolt emigrating within each stratum:

$$\hat{U}_h = \frac{u_h(M_h + 1)}{m_h + 1} \tag{3}$$

where,

U_h = total number of smolt in stratum h, minus observed mortality;
u_h = number of unmarked smolt recaptured in stratum h;

Variance of the exploitation rate estimate was calculated as:

$$v\left(\hat{U}_h\right) = \frac{(M_h + 1)(u_h + m_h + 1)(M_h - m_h)u_h}{(m_h + 1)^2(m_h + 2)} \tag{4}$$

Smolt AWL samples for each stratum were used to estimate the number and size of smolt within each age class. The percentage for each age class was multiplied by the smolt estimate in each stratum to determine the emigration by age by stratum. Each age class of smolt in each stratum was summed to provide a total estimate by age, and total estimates by age were summed to provide an estimate of the total smolt emigration.

Limnological Assessment

Sampling and laboratory analysis methods were adopted from Schrof et al. (2000).

Lake Sampling Protocol

Five limnological surveys of Afognak Lake were conducted at approximately 4-5 week intervals from May to September, 2004. Two stations, marked with anchored mooring buoys, were sampled from a float-equipped aircraft during each survey (Figure 2). Zooplankton samples were collected at both stations, but water samples were only collected at Station 1. Two water samples for general chemistry and nutrient analysis were collected during each survey, an epilimnion sample taken 1 m below the water surface, and hypolimnion sample taken about 2 m above the lake bottom. Sampling was done with a 6-L opaque Van Dorn sampler, and the epilimnion and hypolimnion samples were emptied into separate, pre-cleaned polyethylene carboys, which were kept cool and dark in the float of the plane until processed at the laboratory in Kodiak. Vertical zooplankton hauls were made at each station using a 0.2 m diameter conical net with 153 µm mesh. The net was pulled manually at a constant speed (~0.5 m sec^{-1}) from approximately 2 m off the lake bottom to the surface. The contents from each tow were emptied into a 125-ml polybottle and preserved in 10% neutralized formalin.

General Water Chemistry and Nutrients

For analysis of color and dissolved inorganic nutrients, a portion of each sample was filtered through a rinsed 47 mm-diameter Whatman GF/F cellulose fiber filter and stored frozen in phosphate free soap-washed poly bottles. Frozen filtered water was also used for analysis of total phosphorus (TP), total Kjeldahl nitrogen (TKN), and general water chemistry, and these measurements were also made for frozen unfiltered and refrigerated (4^{o} C) water stored in clean poly bottles (Koenings et al. 1987). The pH of water samples was measured with an Orion 499A meter, while alkalinity (mg L^{-1} as $CaCO_3$) was determined from 100-ml of water titrated with 0.02 N H_2SO_4 to a pH of 4.5 and measured with a pH meter (AHPA 1985).

Reactive silicon was determined using the method of ascorbic acid reduction to molybdenum-blue after Stainton et al. (1977). Total filterable phosphorus (TFP) and filterable reactive phosphorus (FRP) were determined by the molybdate blue-ascorbic acid method (Murphy and Riley 1962) modified by Eisenreich et al. (1975). TP was analyzed after potassium persulfate-sulfuric acid digestion using the FRP procedure (Eisenreich et al. 1975). Samples for nitrate + nitrite ($NO_3^- + NO_2^-$) and ammonia (NH_4^+) were analyzed on a Spectronic Genesys 5 Spectrophotometer using the cadmium reduction and phenylhypochlorite methods outlined in Stainton et al. (1977). Analysis of TKN was completed using the Macro-Kjeldahl/Phenate methods described in Clesceri et al. (1998) in converting nitrogen to ammonia. This determines the concentrations of organic nitrogen and total ammonia. Total nitrogen (TN), the sum of TKN and nitrate + nitrite, was calculated for each sample in addition to the ratio of TN to TP (TN:TP).

Chlorophyll *a*

For chlorophyll *a* (chl *a*) analysis, 1.0 L of water from each sample was filtered through a Whatman GF/F filter under 15 psi vacuum pressure. Approximately 2 ml of magnesium chloride ($MgCO_3$) were added to the final 50 ml of water near the end of the filtration process. Filters were stored frozen and in individual plexiglass slides until analyzed. Filters were then ground in 90% buffered acetone using a mechanical tissue grinder, and the resulting slurry was refrigerated in separate 15-ml glass centrifuge tubes for 4 hours to ensure maximum pigment extraction. Pigment extracts were centrifuged, decanted, and diluted to 15 ml with 90% acetone (Koenings et al. 1987). The extracts were analyzed fluorometrically with a Turner 112 fluorometer equipped with a F4T5B lamp and calibrated with purified chl *a* (Sigma Chemical).

Zooplankton

For zooplankton analysis, cladocerans and copepods were identified according to taxonomic keys in Pennak (1989) and Thorp and Covich (1991). Zooplankton were and measured in triplicate 1 ml subsamples taken with a Hansen-Stempel pipette and placed in a Sedgewick-Rafter counting chamber. Lengths from a minimum of 15 animals of each species or group (typically animals are grouped at the genus level) were measured to the nearest 0.01 mm, and the mean was calculated. Biomass was estimated from species-specific linear regression equations between length and dry weight derived by Koenings et al. (1987). Zooplankton data from the two stations were averaged for each survey.

RESULTS

Smolt Assessment

Enumeration and Sampling

Smolt trapping was conducted a total of 54 days from 11 May to 3 July 2004. During this period, 67,528 sockeye salmon smolt were captured (Table 2). The greatest daily sockeye salmon smolt catch was obtained 5 June when 5,259 smolt were captured (Table 2; Figure 3). Large daily smolt catches were also obtained 24 May (4,231) and 7 June (4,988).

Age, Weight, and Length Sampling

Of the 1,452 sockeye salmon smolt sampled for AWL data, all but one were assigned ages (Table 3). Of these, 94.4 % were age-1. smolt and 5.6% were age-2. smolt. During the first two-weeks of the emigration (11-26 May), samples were composed of 83.9% age-1. and 16.1% age-2. smolt. Age-1. smolt continued to be the dominate age class found in the samples collected after 26 May, and by early June, 94-100% of all smolt sampled were age-1. smolt (Figure 4).

Age-1. smolt had a mean weight of 3.6 g (range – 2.6 g to 5.3 g), a mean length of 75.7 mm (range - 70.6 mm to 84.1 mm), and a mean condition factor of 0.80 (range - 0.74 to 0.89; Table 4). Age-2. smolt had a mean weight of 3.6 g (range - 3.4 g to 3.7 g), a mean length of 78.7 mm (range – 77.2 mm to 80.5 mm), and a mean condition factor of 0.74 (range - 0.71 to 0.75).

Trap Efficiency and Population Estimates

Five mark-recapture experiments were conducted during the sockeye salmon smolt emigration period (Table 2). Trap efficiencies ranged from 10.7% for the first experiment (20 to 26 May) to 30.1% for the third experiment (4 to 11 June). Mean trap efficiency for all experiments was 18.6%.

The total number of sockeye salmon smolt emigrating from the Afognak Lake system in 2004 was estimated to be 430,004 (95% C.I. 371,905 - 488,104; Table 5). The emigration was composed of 387,584 age-1. (90.1%) and 42,420 age-2. (9.9%) smolt (Table 6).

Limnological Assessment

General Water Chemistry and Nutrients

Hydrogen ion concentrations (pH) averaged 6.9 units at the epilimnion (1 m) and 6.8 units at the hypolimnion (18 m) with little seasonal variation (Table 7). Alkalinity levels (measured as $CaCO_3$) ranged from 10.0 mg L^{-1} to 12.5 mg L^{-1} and averaged 11.2 mg L^{-1} throughout the water column. Results from the pH and alkalinity tests from Afognak Lake were consistent with historical data from other Kodiak archipelago lakes (Schrof and Honnold 2003).

Seasonal silica concentrations ranged from 2,465.1 to 3,271.8 μg L^{-1} and averaged 2,839.0 μg L^{-1} (Table 7). Concentrations were similar at 1 and 18 m, and did not vary much during the sampling season. Uniform concentrations were not surprising, since Afognak Lake is relatively shallow and was probably mixed throughout the season. The highest concentrations were observed in May and August from samples taken at 18 m.

Seasonal mean TP concentrations in the epilimnion (1 m) ranged from 2.7 to 11.5 μg L^{-1} and averaged 6.2 μg L^{-1} (Table 8). Seasonal inorganic phosphorous concentrations of TFP were quite varied among samples (Table 8). TFP concentrations ranged from 1.6 μg L^{-1} (epilimnion and hypolimnion on separate sampling dates) to 21.1 μg L^{-1} (hypolimnion) and averaged 5.3 μg L^{-1}. FRP concentrations ranged from 0.8 to 9.7 μg L^{-1} and averaged 2.7 μg L^{-1}. The highest concentration and greatest seasonal variations for TFP and FRP were measured in the hypolimnion.

Nitrogen levels were measured in three forms: TKN, NO_3^- + NO_2^-, and NH_{4+}. The seasonal mean TKN was 169 μg L^{-1}, and the greatest seasonal variation (largest standard deviation) was between May and June samples (Table 8). Seasonal NH_{4+} levels averaged 8.5 μg L^{-1} in the epilimnion and 19.0 μg L^{-1} in the hypolimnion. Little seasonal variation occurred in epilimnion samples, although NH_{4+} levels continuously rose. Greater variation in NH_{4+} levels occurred in the hypolimnion. Seasonal NO_2 + NO_3 levels ranged from 20.2 and 116.3 μg L^{-1} and averaged 70.3 μg L^{-1} (Table 8). TN concentrations in the epilimnion ranged from 138.4 to 387.8 μg L^{-1} and averaged 229.7 μg L^{-1}. The seasonal TN:TP ratio, by weight, averaged 112.2:1 (Table 8).

Chlorophyll *a*

Seasonal chl *a* concentrations ranged from 0.32 μg L^{-1} (hypolimnion) to 1.28 μg L^{-1} (epilimnion) and averaged 0.93 μg L^{-1} throughout the water column (Table 7). Higher chl *a* concentrations were consistently found in the epilimnion.

Zooplankton

Zooplankton mean density was 104,291 animals per m^{-2} (Table 9). All zooplankton identified were crustaceans commonly referred to as either cladocerans (*Order* Anomopoda and Ctenopoda) or copepods (*Order* Calanoida, Cyclopoida, and Harpacticoida). Cladocerans were the predominate zooplankter (54.6% of mean) in samples, with the genus *Bosmina* being most abundant (44.8% of mean). The other two identified cladoceran genera, *Daphnia* and *Holopedium*, were much less abundant (9.7% of mean). Of the copepods, the genus *Epischura* was most abundant (24.2%) followed in abundance by a group called “Other copepods” which consisted mostly of the genus *Harpaticus* and various unidentified, nauplii (larvae). The copepod genus *Cyclops*, considered an important member of the zooplankton community in sockeye salmon lakes, were not very abundant (5.5% of mean). There were almost twice as many cladocerans in samples collected at Station 1 (74,645) than in samples from station 2 (39,339), while copepod densities were similar at both stations. This resulted in cladocerans accounting for most of the average zooplankter density at Station 1 (61.2%), and copepods accounting for a slightly higher density at Station 2 (54.6%).

Zooplankton mean biomass was 102.9 mg per m^{-2} (Table 9). While cladocerans again predominated (51.7%), the difference in biomass between cladocerans and copepods were less than those in the density levels due to the larger size of copepods (Table 9). The copepod genus *Epischura* represented the greatest percentage of biomass (39.0%), followed by the cladoceran genus *Bosmina* (38.0%). The remaining biomass was mostly comprised of *Daphnia* (9.7%), *Cyclops* (7.6%), and *Holopedium* (3.9%). Cladocerans comprised most of the average biomass at Station 1 (60.9%), while copepods comprised most of the biomass at Station 2 (61.4%).

The copepod *Diaptomus* was the largest zooplankter, having a mean length of 0.91 mm (Table 9). While the copepods *Epischura* (0.70 mm mean length) and *Cyclops* (0.64 mm mean length) were smaller than *Diaptomus*, they were still larger than any of the cladocerans. *Daphnia*, the largest cladoceran (0.60 mm mean length) was only slightly smaller than the smallest copepod, *Cyclops*, but *Holopedium* (0.46 mm) and *Bosmina* (0.30 mm) were considerably smaller.

DISCUSSION

Smolt Assessment

Prior to conducting this study, we designed and conducted a feasibility study in 2003 based on results from smolt studies conducted on the Afognak River in 1990 and 1991 (Honnold and Schrof 2004). For the pilot study, we used a different type of smolt trap than was used in 1990 and 1991, and set it in towards the middle of the river where water flow and velocity were greater. We made these changes because smolt estimates in both 1990 and 1991 seem to have been much too low, based on what we felt were reasonable survival assumptions. These changes appeared to work, since mean trap efficiency was 19.9% in 2003. In 2004, we fished the same smolt trap in approximately the same location and obtained a mean trap efficiency of 18.6%. While weekly trap efficiency varied within both years, the similar mean trap efficiencies for both years suggests reliable comparisons of annual smolt production can be made.

We calculated the number of smolt that would be expected to emigrate in 2003 based on survival assumptions applied to the 2000 and 2001 escapements. Similarly, we projected that the 2001 escapement of 24,271 adults would produce about 446,000 smolt and the 2002 escapement of

19,520 adults would produce approximately 359,000 smolt (Honnold and Schrof 2004; Table 10). Apportioning these smolt estimates by average age (90.1% age-1. and 9.9% age-2.) resulted in emigrations of 323,000 age-1. smolt (brood year 2002) and 44,000 age-2. smolt (brood year 2001) in 2004. Thus, approximately 367,000 smolt were expected to emigrate from the system in 2004. The projection was about 15% (63,000 smolt) lower than our 2004 mark-recapture estimate of 430,000 smolt, but very close to the lower bound (372,000) of the 95% confidence interval.

The 2004 emigration was dominated by age-1. smolt (90.1%) with only a small age-2. smolt component (9.9%). We observed a similar trend in 2003, although age-1. smolt comprised a smaller component of the population (66%; Honnold and Schrof 2004). Typically, systems that produce a greater proportion of age-1. smolt generally have favorable freshwater rearing conditions. Increased proportions of older smolt could result from decreased lake productivity or the presence of more juvenile salmon than the system is able to support (Barnaby 1944; Krokhin 1957; Burgner 1964; Foerster 1968; Koenings et al. 1993). When the juvenile population begins to exceed the rearing capacity of a system, a greater proportion of the population must spend two or more years in freshwater before growing large enough to transform into smolt (Honnold and Schrof 2004). Based on the dominance (90.1%) of age-1. smolt emigrating from Afognak Lake in 2004, freshwater rearing capacity has not been exceeded and was able to support the juvenile population produced from recent escapements.

Age, weight, and length data for the 2004 smolt emigration also suggest that rearing conditions in Afognak Lake were not being exceeded (Table 4). Mean size and condition of age-1. smolt sampled in 2004 (n=1,370; 3.6 g, 75.7 mm, 0.80 K) were slightly less than that of age-1. smolt sampled in 2003 (n=1,031; 4.1 g, 79.1 mm, 0.82 K), but were greater than that of age-1. smolt in both 1991 (n=1,895; 3.1 g, 72.9 mm, 0.78 K) and 1990 (n=544; 2.5 g, 69 mm, 0.76 K) emigrations. Additionally, age-1. smolt mean size and condition during other past years, particularly years in which sampling probably covered most of the smolt emigration (2000, 1999, and 1995) were generally similar to that for 2004 (Appendix B; Schrof and Honnold 2003). Within both the 2003 and 2004 seasons, age-2. smolt had greater mean lengths but the same mean weights as age-1. smolt. This same pattern occurred most years, and may result from spring growth of later migrating age-1. smolt as the lake temperature increases. For example, in 2004, age-1. smolt increased in size from 2.6 g and 70 mm in mid-May to 5.3 g and 84 mm in late June. Conversely, all age-2. smolt emigrate in May and grow very little during that time.

Emigration timing of sockeye salmon smolt from Afognak Lake in 2004 was similar to timing in 2003 as well as to the timing observed for smolt emigrating from Malina and Little Kitoi lakes, two other systems on Afognak Island (Figure 4; Appendices C-E). Smolt emigration from all these systems generally begins in mid-May, peaks early to mid-June, and is essentially over by early July. The only exception to this pattern occurred at Little Kitoi Lake in 1995, where smolt emigration showed an extremely large peak in August after declining to very low levels in late June and remaining that way through July. As has been documented for other systems (Barnaby 1944; Krogius and Krokhin 1948; Burgner 1962), older and larger smolts tended to migrate earlier from the Afognak Lake system.

Limnological Assessment

Seasonal water chemistry (pH, alkalinity) showed little variation in Afognak Lake in the 2004 sampling, which is consistent with results from past years (Schrof and Honnold 2003).

Seasonal nutrient levels showed a greater amount of variation in 2004, but this was also mostly consistent with results from past years (White et al. 1990, Schrof and Honnold 2003). Silica, the only dissolved nutrient measured in 2004, showed less seasonal variation than either phosphorus or nitrogen. This is not surprising since both nitrogen and phosphorus are important components of phytoplankton while silica is generally only a minor component. The total nitrogen and phosphorus ratio of 112:1 in 2004 reflects a low phosphorus concentration relative to nitrogen. While White et al. (1990) found phosphorus concentration relative to nitrogen (64:1), it was still considered phosphorus deficient since optimum TN:TP ratios range from 10:1 to 20:1 (Honnold et al. 1996; Honnold and Schrof 2001).

The 2004 seasonal mean algal standing crop (chl *a*) of Afognak Lake (0.93 μg $L^{-1)}$ is low but typical for oligotrophic Alaska lakes, which have chl *a* concentrations below 1.5 μg L^{-1} (Honnold et al. 1996). The chl *a* levels measured by White et al. (1990) in the epilimnion (0.97 μg L^{-1}) and hypolimnion (0.94 μg L^{-1}) during 1987-1989 were very similar to 2004 levels. Chl *a* levels during 1990-1998 were probably greatly influenced by lake enrichment activities (1990-2000), which presumably elevated these levels. Levels measured during 1990-1998 ranged from 0.10 to 4.20 μg L^{-1} (Schrof and Honnold 2003). However, chl *a* concentrations measured at other lakes on Afognak Island also tend to show a high degree of variation (Schrof and Honnold 2003).

Seasonal mean zooplankton abundance and biomass estimates at Station 2 were about 29% less than estimates from Station 1 (Table 9), which is likely due to Station 2 being closer to the lake outlet. Lake water residence time is estimated to be only 0.4 years, so rapid lake flushing may remove zooplankton quicker than they can be replenished through reproduction (White et al. 1990). Rapid flushing may also affect nutrient availability for phytoplankton, which could affect zooplankton production. From 1988-1997, zooplankton tows were made at both stations, but in 1998, Station 2 was no longer sampled (Appendix F). During the time period both stations were sampled, zooplankton numbers were always consistently lower at Station 2 than Station 1. During some years, zooplankton numbers ranged from 8% to 100% less than numbers at Station 1.

Since the zooplankton community serves as the primary forage base in lakes for juvenile sockeye salmon, total zooplankton abundance and biomass are often estimated to assess juvenile sockeye salmon production potential (Koenings et al. 1987). Overall, zooplankton abundance in 2004 was lower than that estimated in 2003 (Table 9; Appendix F). However, juvenile sockeye salmon prefer to eat cladocerans rather than copepods, so cladoceran abundance is a better indicator of evaluating sockeye salmon forage (Koenings et al. 1987; Kyle 1996).

The cladoceran *Daphnia* was more abundant in 2004 than it had been in the preceding five years at Station 1 (Table 9; Appendix F). This is encouraging, since *Daphnia* are the primary prey for juvenile sockeye salmon and their increase probably indicates a lack of excessive foraging by juvenile sockeye salmon (Kyle 1996; Honnold and Schrof 2001). This trend was also seen for the cladoceran *Holopedium*, but not for *Bosmina*, which has fluctuated in abundance during this time period. *Bosmina* are more difficult for juvenile salmon to locate and eat due to its small size (Koenings and Kyle 1997), since *Bosmina* are about half the size of *Daphnia* and about two thirds the size of *Holopedium.* Copepods are usually not as important as a juvenile salmon food item, when cladocerans are present, and copepod abundance was considerably less than cladoceran abundance in 2004. Mean densities of *Diaptomus* at Stations 1 and 2 were generally much less than those observed during the period 1991-2003, while densities of *Epischura* and *Cyclops* were generally similar to observed during that same time period. All three identified copepods were also generally smaller in size in 2004 compared to most of the past years.

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Table 1. Afognak Lake sockeye salmon escapement, harvest, and total run estimates, 1978-2004.

		Harvest				
Year	Escapement	Commercial[a]	Subsistence[b]	Sport[c]	Total	Total Run
1978	52,701	3,414	1,632	524	5,570	58,271
1979	82,703	2,146	2,069	524	4,739	87,442
1980	93,861	28	3,352	524	3,904	97,765
1981	57,267	16,990	3,648	524	21,162	78,429
1982	123,055	21,622	3,883	524	26,029	149,084
1983	40,049	4,349	3,425	524	8,298	48,347
1984	94,463	6,130	3,121	524	9,775	104,238
1985	53,563	1,980	6,804	524	9,308	62,871
1986	48,328	2,585	3,450	524	6,559	54,887
1987	25,994	1,323	2,767	524	4,614	30,608
1988	39,012	14	2,350	524	2,888	41,900
1989	88,825	0	3,859	524	4,383	93,208
1990	90,666	22,149	4,469	524	27,142	117,808
1991	88,557	47,237	5,899	524	53,660	142,217
1992	77,260	2,196	4,638	600	7,434	84,694
1993	71,460	1,848	4,580	524	6,952	78,412
1994	80,570	17,362	3,329	524	21,215	101,785
1995	100,131	67,665	4,390	524	72,579	172,710
1996	101,718	106,141	11,023	258	117,422	219,140
1997	132,050	10,409	12,412	535	23,356	155,406
1998	66,869	26,060	4,690	718	31,468	98,337
1999	95,361	34,420	5,628	237	40,285	135,646
2000	54,064	14,124	7,572	364	22,060	76,124
2001	24,271	0	4,720	169	4,889	29,160
2002	19,520	0	1,279	41	1,320	20,840
2003	27,766	0	604	0	604	28,370
2004	15,181	0	567	10	577	15,758

[a] Statistical fishing section 252-34 (Afognak Bay).

[b] Data from ADF&G subsistence catch database.

[c] Data from ADF&G Sport Fish Division statewide harvest survey (SWHS) for 1992, 1996-2004; SWHS data for other years did not have enough respondents to provide reliable estimates. Four years with reliable data were averaged and entered for years with no data.

Table 2. Sockeye salmon smolt counts, number of samples collected, mark-recapture counts, and trap efficiency ratios from trapping at Afognak River, 2004.

	Catch		Dye Test Period	AWL Sample	Number Marked	Marked Recoveries		Trap Efficiency
Date	Daily	Cumulative	Cumulative	Cumulative	Releases	Daily	Cumulative	(%)
11-May	37	37						
12-May	18	55		12				
13-May	95	150		52				
14-May	134	284						
15-May	117	401						
16-May	243	644		92				
17-May	498	1,142		132				
18-May	911	2,053		172				
19-May	3,584	5,637		212				
20-May	1,515	7,152		252	525	32	32	
21-May	1,793	8,945				6	38	
22-May	1,988	10,933				6	44	
23-May	3,184	14,117		292		5	49	
24-May	4,231	18,348		332		5	54	
25-May	3,220	21,568		372		2	56	
26-May	2,710	24,278	24,278	412		0	56	10.7%
27-May	2,173	26,451		452	547	42	42	
28-May	2,078	28,529				28	70	
29-May	2,168	30,697				23	93	
30-May	2,997	33,694		492		1	94	
31-May	2,590	36,284		532		1	95	
1-Jun	2,171	38,455		572		1	96	
2-Jun	499	38,954		612		0	96	
3-Jun	3,051	42,005	17,727			0	96	17.6%
4-Jun	1,540	43,545		652	700	205	205	
5-Jun	5,259	48,804				6	211	
6-Jun	1,954	50,758		692		0	211	
7-Jun	4,988	55,746		732		0	211	
8-Jun	1,576	57,322		772		0	211	
9-Jun	262	57,584		812		0	211	
10-Jun	259	57,843				0	211	
11-Jun	820	58,663	16,658			0	211	30.1%
12-Jun	1,259	59,922		852	613	97	97	
13-Jun	271	60,193		892		16	113	
14-Jun	210	60,403		932		2	115	
15-Jun	211	60,614		972		2	117	
16-Jun	634	61,248		1,012		2	119	
17-Jun	542	61,790		1,052		0	119	
18-Jun	508	62,298				0	119	
19-Jun	1,451	63,749	5,086			0	119	19.4%

-Continued-

Table 2. (page 2 of 2)

Date	Catch Daily	Catch Cumulative	Dye Test Period Cumulative	AWL Sample Cumulative	Number Marked Releases	Marked Recoveries Daily	Marked Recoveries Cumulative	Trap Efficiency (%)
20-Jun	969	64,718		1,092	581	70	70	
21-Jun	1,021	65,739		1,132		16	86	
22-Jun	741	66,480		1,172		1	87	
23-Jun	289	66,769		1,212		1	88	
24-Jun	108	66,877		1,252		0	88	
25-Jun	133	67,010				0	88	
26-Jun	60	67,070				0	88	
27-Jun	58	67,128		1,292		0	88	
28-Jun	70	67,198		1,332		0	88	
29-Jun	97	67,295		1,372		0	88	
30-Jun	118	67,413		1,412		0	88	
1-Jul	43	67,456		1,452		0	88	
2-Jul	32	67,488				0	88	
3-Jul	40	67,528	3,779			0	88	15.1%
4-Jul	Trap pulled July 4				Average Trap Efficiency =			18.6%

Table 3. Estimated age composition of the Afognak Lake sockeye salmon smolt sampled in each dye test period, 2004.

Stratum	Sample Size		Age 1	Age 2	Age 3	Total
1	411	Percent	83.9	16.1	0.0	100.0
5/12-5/26		Numbers	345	66	0	411
2	200	Percent	94.5	5.5	0.0	100.0
5/27-6/3		Numbers	189	11	0	200
3	200	Percent	98.5	1.5	0.0	100.0
6/4-6/11		Numbers	197	3	0	200
4	240	Percent	99.6	0.4	0.0	100.0
6/12-6/19		Numbers	239	1	0	240
5	400	Percent	100.0	0.0	0.0	100.0
6/20-7/3		Numbers	400	0	0	400
Total	1,451					

Table 4. Mean weight, length, and condition factor of Afognak Lake sockeye salmon smolt samples by age and week, 2004.

			Weight (g)		Length (mm)		Condition	
Age	Statistical Week	Sample Size	Mean	Standard Error	Mean	Standard Error	Mean	Standard Error
1	20	63	2.6	0.04	70.6	0.31	0.74	0.005
1	21	168	2.7	0.02	71.5	0.20	0.74	0.004
1	22	191	2.7	0.02	71.2	0.18	0.74	0.003
1	23	190	2.8	0.02	72.0	0.17	0.76	0.003
1	24	198	3.1	0.03	73.7	0.19	0.78	0.003
1	25	200	4.1	0.03	78.3	0.19	0.86	0.004
1	26	200	4.5	0.03	81.3	0.17	0.84	0.003
1	27	160	5.3	0.04	84.1	0.19	0.89	0.004
Total		1,370	3.6	0.03	75.7	0.15	0.80	0.002
2	20	29	3.7	0.12	79.0	0.71	0.75	0.013
2	21	31	3.5	0.09	78.5	0.68	0.73	0.007
2	22	9	3.7	0.18	79.2	0.92	0.73	0.013
2	23	10	3.4	0.07	77.2	0.68	0.73	0.017
2	24	2	3.7	0.40	80.5	0.50	0.71	0.063
Total		81	3.6	0.06	78.7	0.39	0.74	0.006

Table 5. Population estimate of the sockeye salmon smolt emigration from Afognak Lake, 2004.

Stratum	Beginning	Ending	Catch	Released	Recaptured	Estimate	Variance	95% Confidence Interval	
(h)	Date	Date	(u_h)	(M_h)	(m_h)	(U_h)	var (U_h)	lower	upper
1	5/11	5/26	24,278	525	56	224,039	7.73E+08	169,530	278,548
2	5/27	6/3	17,727	547	96	100,148	8.47E+07	82,111	118,186
3	6/4	6/11	16,658	700	211	55,081	1.01E+07	48,864	61,299
4	6/12	6/19	5,086	613	119	26,023	4.61E+06	21,815	30,231
5	6/20	7/3	3,779	581	88	24,712	5.88E+06	19,958	29,466
Total						430,004	8.79E+08	371,905	488,104
						SE=	29,643		

Table 6. The Afognak Lake sockeye salmon smolt emigration estimate based on percents by age class and dye test period, 2004.

Stratum	Dye Test Period	Age 1.	Age 2.	Age 3.	Total
1	(5/11-5/26)	188,062	35,977	0	224,039
2	(5/27-6/3)	94,640	5,508	0	100,148
3	(6/4-6/11)	54,255	826	0	55,081
4	(6/12-6/19)	25,915	108	0	26,023
5	(6/20-7/3)	24,712	0	0	24,712
		387,584	42,420	0	430,004
		90.1%	9.9%	0.0%	100.0%

Table 7. General water chemistry and algal pigment concentrations in Afognak Lake, 2004.

Date	Station	Water Sample Depth	pH (units)	Alkalinity (mg L^{-1})	Silicon (μg L^{-1})	Chlorophyll *a* (μg L^{-1})
10-May	1	1	7.0	11.0	3271.8	0.96
10-May	1	18	7.0	10.5	3186.2	0.64
7-Jun	1	1	6.9	10.5	2963.2	1.28
7-Jun	1	18	6.9	10.0	2990.7	0.64
6-Jul	1	1	7.0	11.5	2554.7	0.96
6-Jul	1	18	6.8	11.0	2704.7	0.32
11-Aug	1	1	6.8	12.5	2465.1	1.28
11-Aug	1	18	6.6	12.0	3138.8	0.64
20-Sep	1	1	6.8	11.5	2565.6	1.28
20-Sep	1	18	6.7	11.0	2549.6	1.28
Average	1	1 & 18	6.8	11.2	2839.0	0.93
Average	1	1	6.9	11.4	2764.1	1.15
STDEV	1	1	0.1	0.7	342.8	0.18
Average	1	18	6.8	10.9	2914.0	0.70
STDEV	1	18	0.1	0.7	277.1	0.35

Table 8. Seasonal phosphorus and nitrogen concentrations in Afognak Lake, 2004.

Date	Station	Depth (m)	Total filterable-P (μg L^{-1})	Filterable reactive-P (μg L^{-1})	Total-P (μg L^{-1})	Ammonia (ug L^{-1})	Total Kjeldahl nitrogen (μg L^{-1})	Nitrate + Nitrite (μg L^{-1})	Total-N (μg L^{-1})	TN:TP ratio
10-May	1	1	4.0	2.2	4.8	6.5	306.0	81.8	387.8	178.9
10-May	1	18	3.1	1.9	3.4	6.6	na	90.0		
7-Jun	1	1	9.8	2.3	11.5	6.6	38.0	100.4	138.4	26.6
7-Jun	1	18	1.6	9.7	9.3	15.5	na	67.5		
6-Jul	1	1	1.6	0.8	7.8	6.9	128.0	58.3	186.3	52.9
6-Jul	1	18	21.1	1.8	6.8	20.7	na	85.4		
11-Aug	1	1	3.6	2.7	2.7	9.4	236.0	20.2	256.2	210.1
11-Aug	1	18	2.7	2.2	5.1	40.7	na	116.3		
20-Sep	1	1	2.6	1.8	4.3	13	137.0	43.0	180.0	92.7
20-Sep	1	18	2.6	1.8	4.9	11.4	na	39.7		
Average	1	1 & 18	5.3	2.7	6.1	13.7		70.3		
Average	1	1	4.3	2.0	6.2	8.5	169.0	60.7	229.7	112.2
STDEV	1	1	3.2	0.7	3.5	2.8	103.8	31.5	98.0	79.5
Average	1	18	6.2	3.5	5.9	19.0		79.8		
STDEV	1	18	8.3	3.5	2.3	13.2		28.4		

Table 9. Weighted seasonal mean zooplankton density, biomass, and size by station from Afognak Lake, 2004.

Station	*n*		*Epischura*	*Diaptomus*	*Cyclops*	Other Copepods	*Bosmina*	*Daphnia*	*Holopedium*	Other Cladocerans	Total Copepods	Total Cladocerans	Total all zooplankton
1	5	density (no. m^{-2})	23,206	510	6,374	17,284	58,598	11,472	2,771	1,805	47,373	74,645	122,019
		%	19.0%	0.4%	5.2%	14.2%	48.0%	9.4%	2.3%	1.5%	38.8%	61.2%	100.0%
		biomass (mg m^{-2})	36.6	1.4	8.2	0.9	51.7	16.5	5.4	0.0	47.1	73.5	120.7
		%	30.3%	1.2%	6.8%	0.8%	42.8%	13.6%	4.5%	0.0%	39.1%	60.9%	100.0%
		size (mm)	0.69	0.86	0.62	0.55	0.31	0.58	0.48				
2	5	density (no. m^{-2})	27,192	32	5,125	14,875	34,843	2,187	1,624	685	47,224	39,339	86,563
		%	31.4%	0.0%	5.9%	17.2%	40.3%	2.5%	1.9%	0.8%	54.6%	45.4%	100.0%
		biomass (mg m^{-2})	43.6	0.1	7.5	1.0	26.6	3.6	2.7	0.0	52.3	32.8	85.1
		%	51.2%	0.1%	8.9%	1.2%	31.2%	4.2%	3.2%	0.0%	61.4%	38.6%	100.0%
		size (mm)	0.70	0.95	0.66	0.59	0.29	0.62	0.44				
1 & 2		density (no. m^{-2})	25,199	271	5,749	16,080	46,720	6,830	2,197	1,245	47,299	56,992	104,291
Averaged		%	24.2%	0.3%	5.5%	15.4%	44.8%	6.5%	2.1%	1.2%	45.4%	54.6%	100.0%
		biomass (mg m^{-2})	40	1	8	1	39	10	4	0	50	53	102.9
		%	39.0%	0.8%	7.6%	0.9%	38.0%	9.7%	3.9%	0.0%	48.3%	51.7%	100%
		size (mm)	0.70	0.91	0.64	0.57	0.30	0.60	0.46				

Table 10. Afognak Lake sockeye salmon theoretical production of eggs, emergent fry, and smolt by age from brood years 2001 and 2002 and predicted smolt emigration in 2004.

Production		Brood Year		Total
Parameter	Assumption	2001	2002	
Escapement		24,271	19,520	
Females spawning	1:1 sex ratio	12,136	9,760	
Deposited Eggs	2,500 per female[a]	30,338,750	24,400,000	
Emergent Fry	7% egg-to-fry survival[b]	2,123,713	1,708,000	
Smolt	21% fry-to-smolt survival[c]	445,980	358,680	
Smolt Emigrating in 2004	90.1% age-1., 9.9% age-2. (Table 6)	44,152	323,171	367,323

[a]Roelofs (1964)

[b]Average from Drucker (1970) and Koenings and Kyle (1997)

[c]Koenings and Kyle (1997)

Figure 1. This map displays the locations of Kodiak City, and the villages of Port Lions, and Ouzinkie and their proximity to the Afognak Lake drainage on Afognak Island.

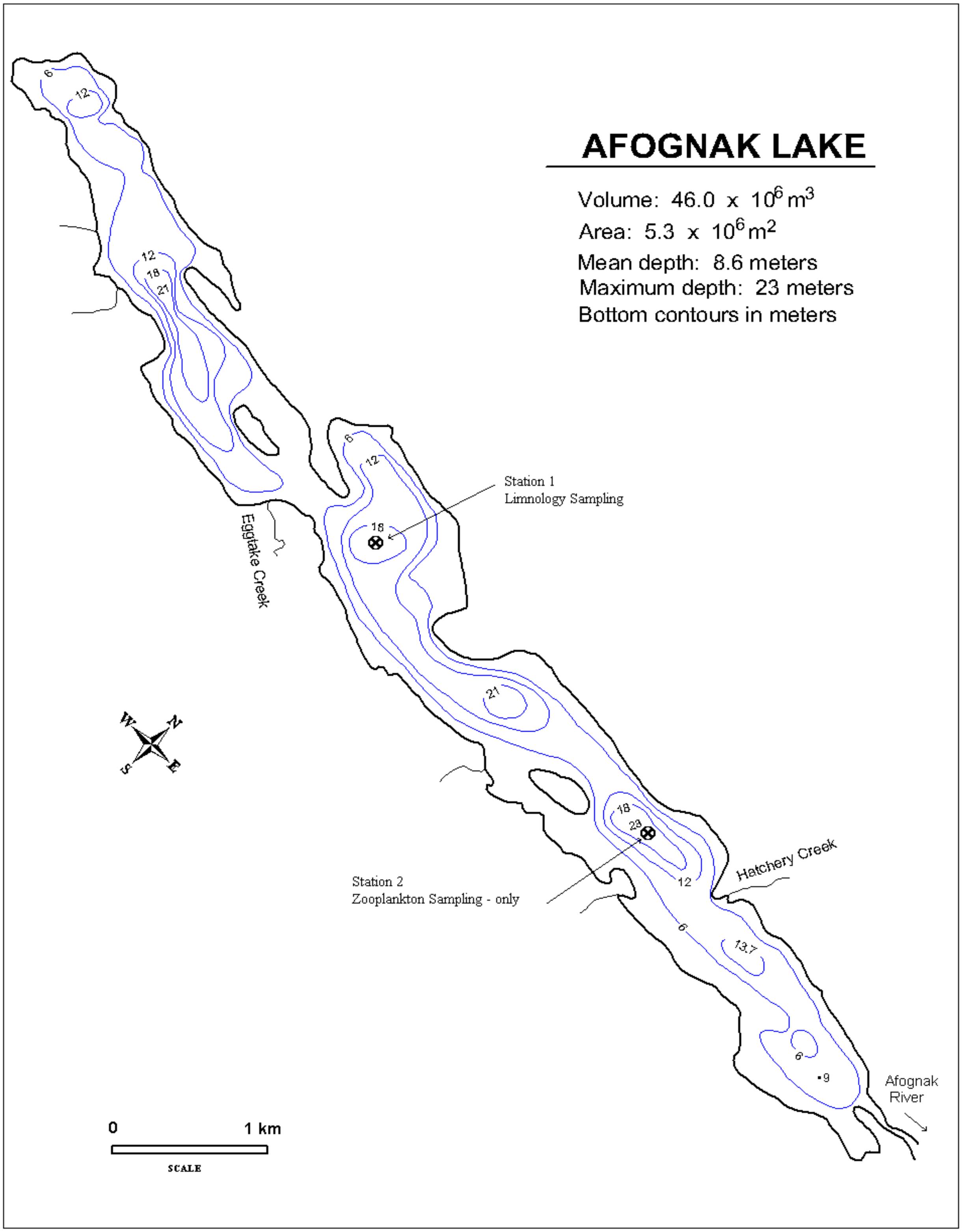


Figure 2. Bathymetric map showing the limnology and zooplankton stations on Afognak Lake.

Figure 3. The smolt trapping system set up in the Afognak River, 2004.

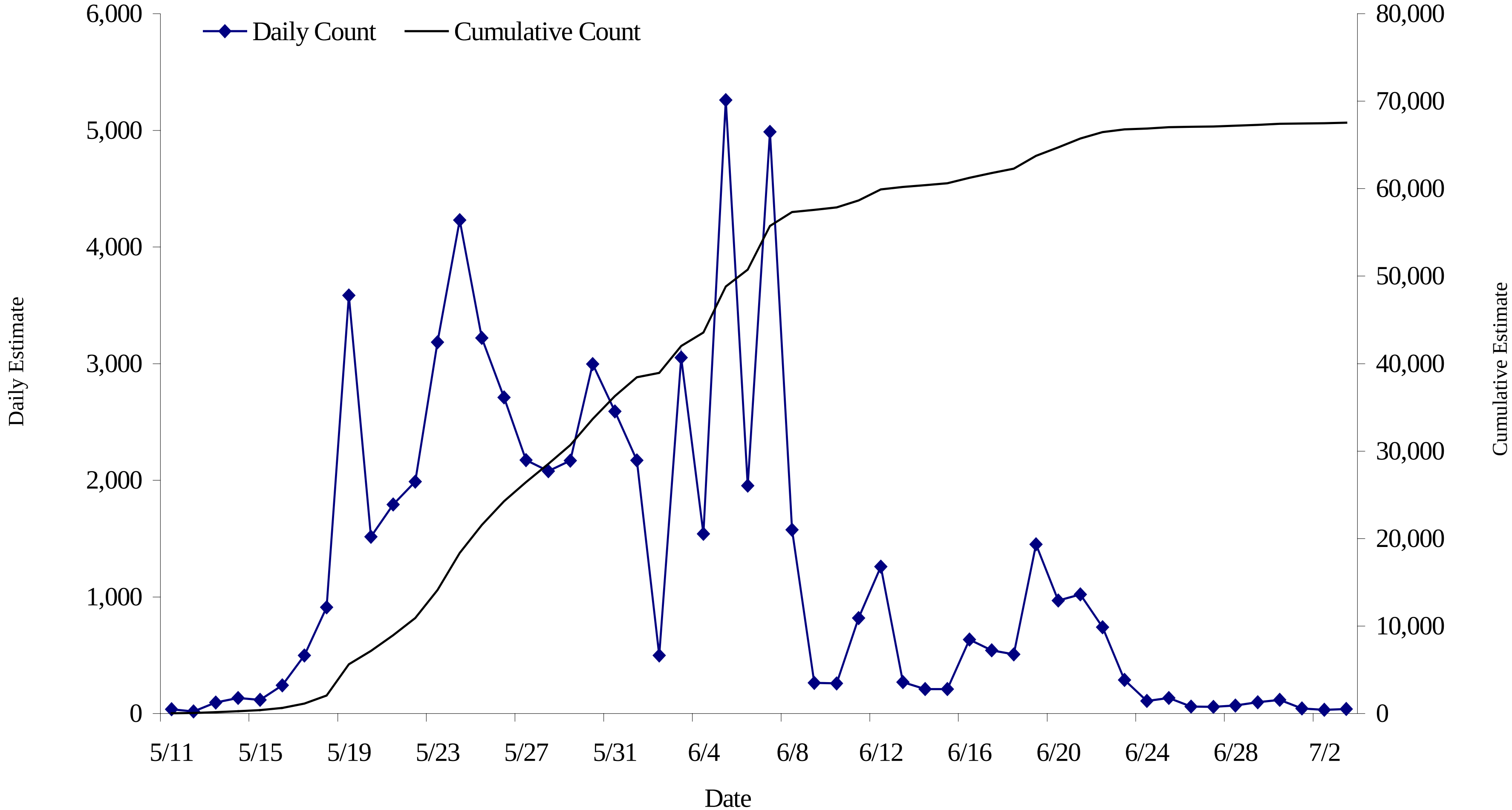


Figure 4. Daily and cumulative sockeye salmon smolt trap catch estimates by day from 11 May to 3 July in the Afognak River, 2004.

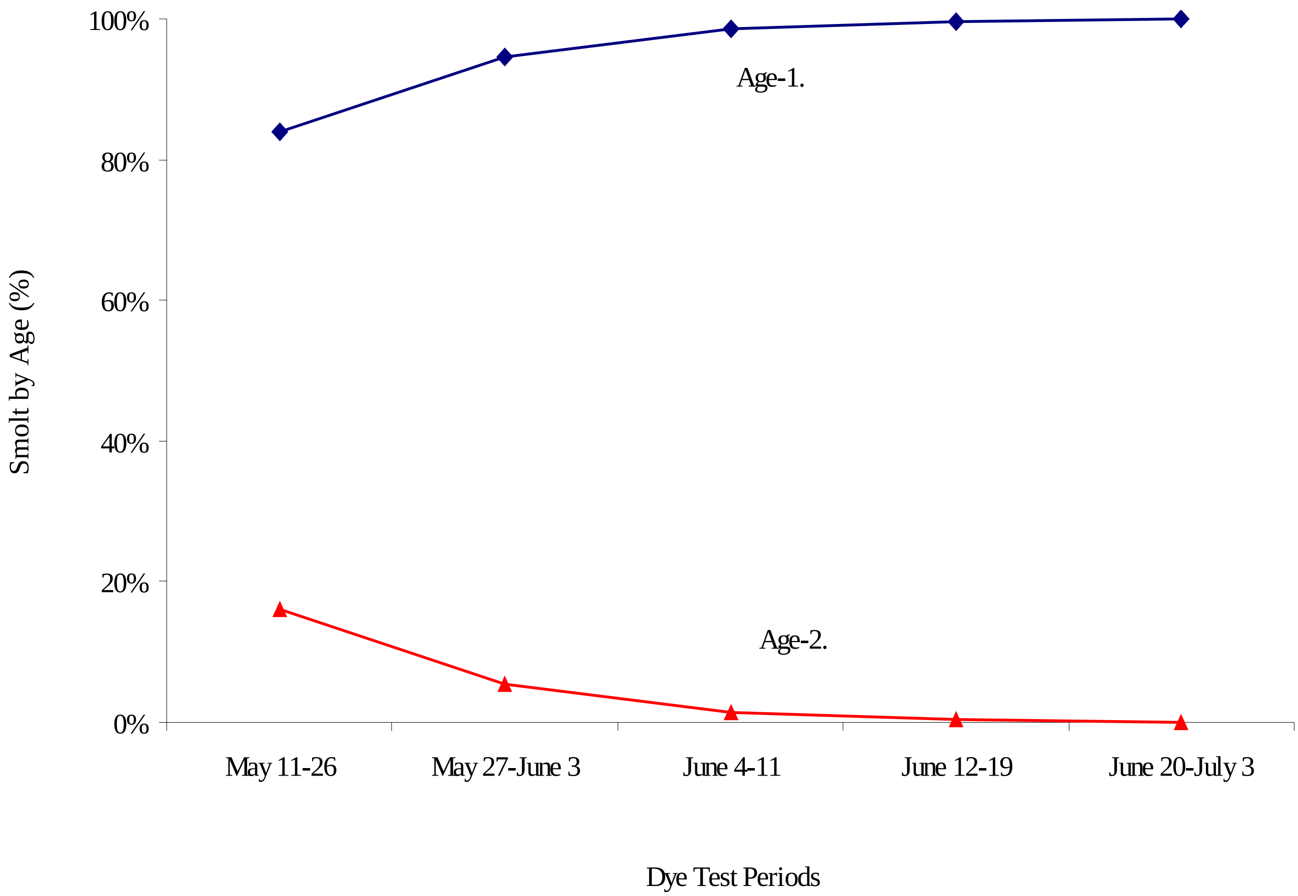


Figure 5. Afognak Lake sockeye salmon smolt sampled during the emigration by age class and dye test period, 2004.

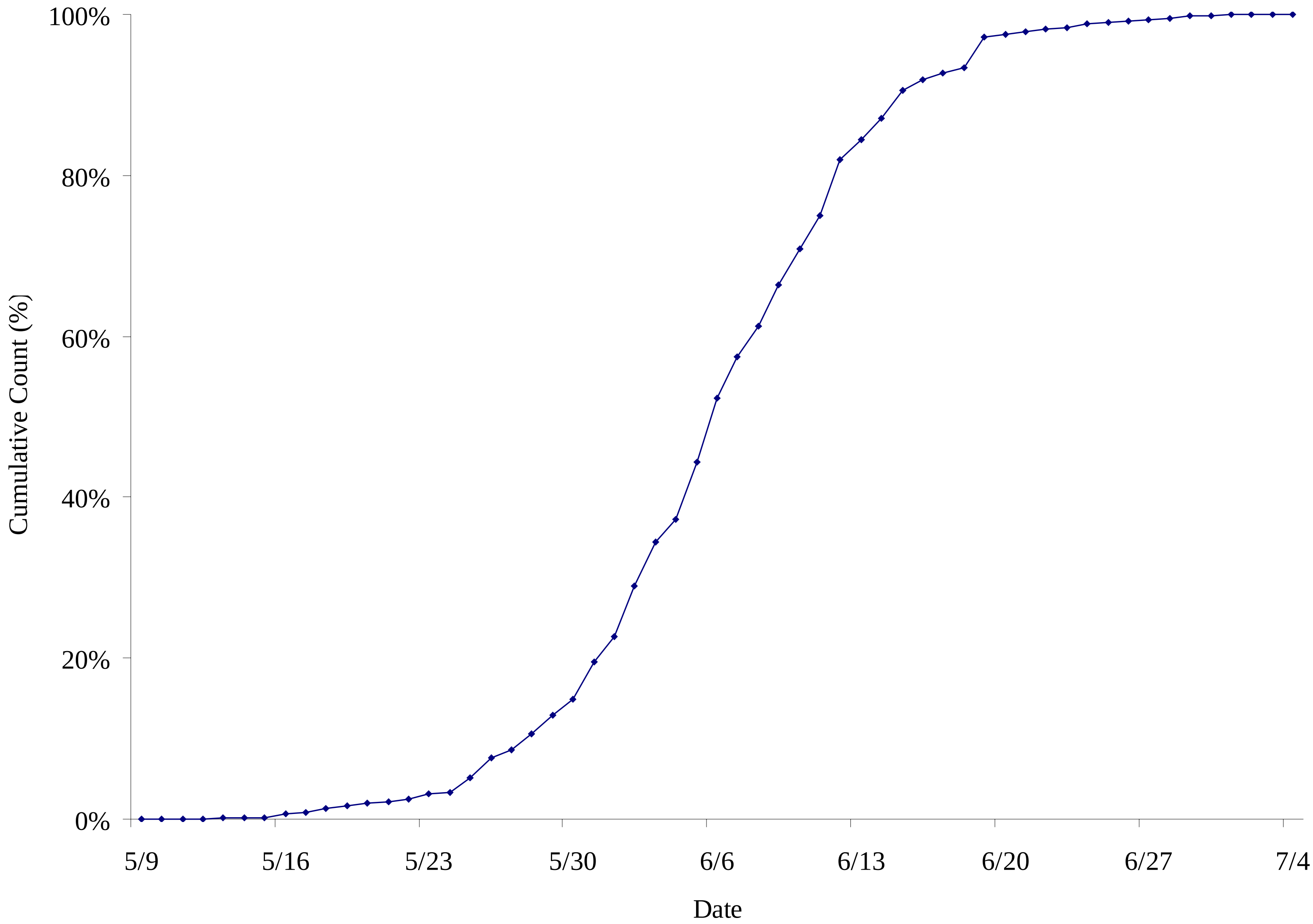
Appendix A. Estimated age composition of the Afognak Lake sockeye salmon escapement, 1987-2003.

Year	Sample Size		Ages 1.1	1.2	2.1	1.3	2.2	3.1	1.4	2.3	3.2	3.3
1987	281	Numbers	1,695	9,797	284	9,609	1,131	0	0	3,863	0	0
		Percent	6.4	37.0	1.1	36.3	4.3	0.0	0.0	14.6	0.0	0.0
1988	933	Numbers	263	23,059	824	9,773	4,488	0	0	429	0	0
		Percent	0.7	59.1	2.1	25.1	11.5	0.0	0.0	1.1	0.0	0.0
1989	1,088	Numbers	13,288	13,404	3,135	35,165	16,314	0	0	7,519	0	0
		Percent	15.0	15.1	3.5	39.6	18.4	0.0	0.0	8.5	0.0	0.0
1990	1,053	Numbers	597	42,314	553	20,518	7,754	0	261	18,613	0	0
		Percent	0.7	46.7	0.6	22.6	8.6	0.0	0.3	20.5	0.0	0.0
1991	1,062	Numbers	295	13,054	196	67,805	3,101	0	0	4,106	0	0
		Percent	0.3	14.7	0.2	76.6	3.5	0.0	0.0	4.6	0.0	0.0
1992	1,025	Numbers	16,362	17,115	7,681	23,096	2,938	90	394	9,526	61	0
		Percent	21.2	22.2	9.9	29.9	3.8	0.1	0.5	12.3	0.0	0.0
1993	852	Numbers	11,837	7,634	12,318	21,667	8,818	53	0	8,965	163	0
		Percent	16.6	10.7	17.2	30.3	12.3	0.1	0.0	12.5	0.2	0.0
1994	840	Numbers	7,703	24,648	3,337	28,385	8,316	125	61	7,708	64	0
		Percent	9.6	30.6	4.1	35.2	10.3	0.2	0.1	9.6	0.1	0.0
1995	848	Numbers	2,281	21,788	837	56,367	10,773	0	149	7,776	0	0
		Percent	2.3	21.8	0.8	56.3	10.8	0.0	0.1	7.8	0.0	0.0
1996	1,119	Numbers	16,340	9,398	2,184	44,744	2,095	0	185	26,427	80	0
		Percent	16.0	9.2	2.1	44.0	2.1	0.0	0.2	26.0	0.1	0.0
1997	1,168	Numbers	5,234	29,004	7,330	47,888	2,351	0	41	14,840	0	0
		Percent	4.9	27.1	6.9	44.8	2.2	0.0	0.0	13.9	0.0	0.0
1998	1,240	Numbers	13,039	5,483	5,082	31,763	7,289	134	267	3,812	0	0
		Percent	19.5	8.2	7.6	47.5	10.9	0.2	0.4	5.7	0.0	0.0
1999[a]	1,195	Numbers	661	30,350	427	6,911	30,943	72	202	5,466	456	0
		Percent	0.9	40.2	0.6	9.1	41.0	0.1	0.3	7.2	0.6	0.0
2000	1,161	Numbers	887	1,276	171	8,302	3,084	0	0	37,238	1,753	0
		Percent	1.7	2.4	0.3	15.6	5.8	0.0	0.0	70.0	3.3	0.0
2001	790	Numbers	137	2,393	833	5,473	676	1,877	0	9,328	0	0
		Percent	0.7	11.4	4.0	26.2	3.2	9.0	0.0	44.6	0.0	0.0
2002	238	Numbers	20	215	683	6,871	4,626	176	0	976	5,934	0
		Percent	0.1	1.1	3.5	35.2	23.7	0.9	0.0	5.0	30.4	0.0
2003	498	Numbers	1,148	6,273	66	233	7,141	0	0	8,229	770	3,907
		Percent	4.1	22.6	0.2	0.8	25.7	0.0	0.0	29.6	2.8	14.1
Average		Numbers	5,399	15,130	2,702	24,975	7,167	149	92	10,284	546	230
1987-2003		Percent	7.1	22.4	3.8	33.8	11.6	0.6	0.1	17.3	2.2	0.8

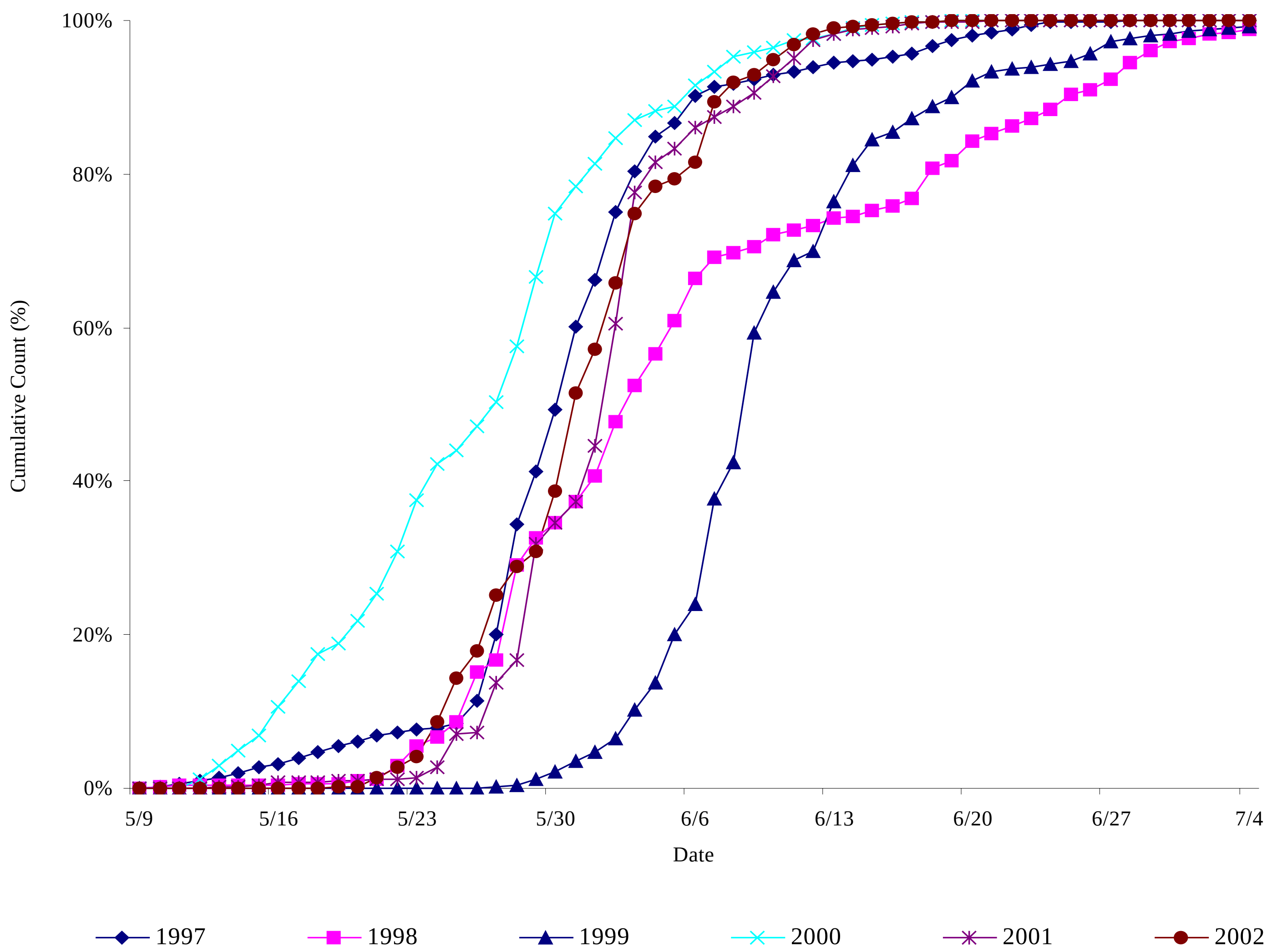
[a] In 1999, 72 (0.1%) sockeye salmon were aged 0.4.

Appendix B. Mean weight, length, and condition coefficient by age for sockeye salmon smolt sampled at Afognak Lake, 1987-2001, and 2003.

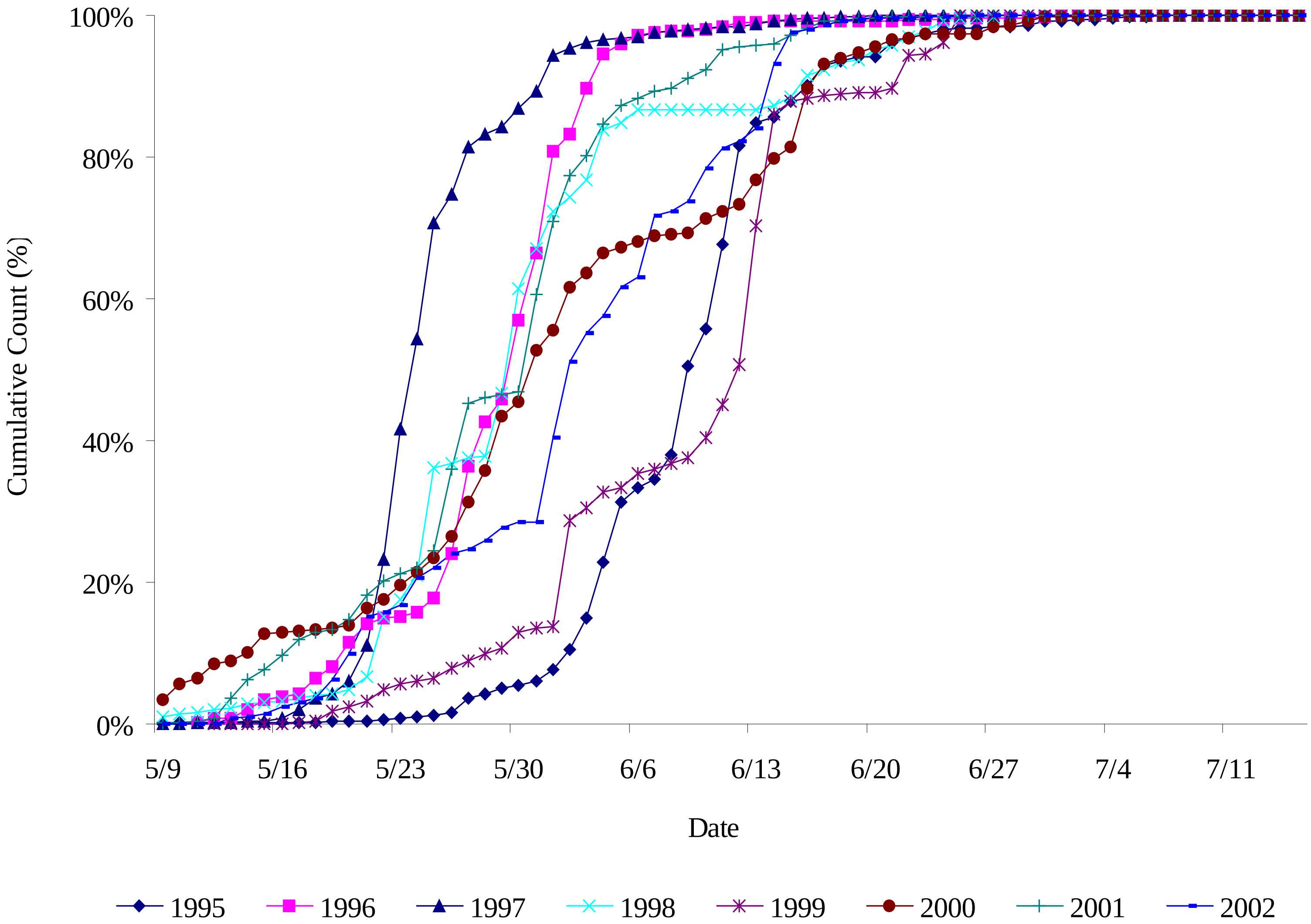
		Age-1				Age-2			
Year	Sampling Period	n	Weight (g)	Length (mm)	Condition (K)	n	Weight (g)	Length (mm)	Condition (K)
1987	8-Jun	36	3.6	74.9	0.85	186	3.6	79.3	0.86
1988	15-Jun	202	4.1	77.9	0.90	0			
1989	15-Jun	208	4.1	76.8	0.91	2	5.2	78.0	1.10
1990	May 23-June 24	544	2.5	68.8	0.76	21	3.4	77.3	0.73
1991	May 13-June 26	1,895	3.1	72.9	0.78	176	3.9	78.3	0.81
1992	June 7-20	268	3.8	77.0	0.82	37	3.8	76.9	0.83
1993	May 24-30	274	3.0	72.7	0.78	21	3.3	74.8	0.79
1994	May 17-23	138	3.0	72.0	0.81	142	4.7	84.3	0.79
1995	May 31-June 13	394	2.8	69.4	0.84	5	3.6	78.8	0.74
1996	June 5-11	54	4.6	80.9	0.87	339	4.8	81.6	0.88
1997	May 24-30	76	4.3	81.7	0.78	122	4.4	82.1	0.79
1998	May 24-30	116	2.6	66.4	0.82	46	6.6	88.0	0.90
1999	May 31-June 6	96	2.8	74.6	0.66	98	2.1	66.6	0.69
2000	May 31-June 13	84	4.9	81.5	0.89	100	5.6	85.3	0.89
2001	June 11-13	44	7	90.1	0.93	17	5.8	85.6	0.92
2003	May 12-July 3	1,031	4.2	79.1	0.82	383	4.2	81.4	0.77



Appendix C. Sockeye salmon smolt emigration timing from Afognak Lake, 2003.



Appendix D. Sockeye salmon smolt emigration timing from Malina Lakes, 1997-2002.



Appendix E. Sockeye salmon smolt emigration timing from Little Kitoi Lake, 1995-2002.

Appendix F. Weighted mean zooplankton density, biomass, and size for Afognak Lake, stations 1 and 2, 1987-2003.

Station 1		*Epischura*			*Diaptomus*			*Cyclops*			*Bosmina*			*Daphnia*			*Holopedium*			TOTALS	
Year	No. Samples	Density (no/m^2)	Biomass (mg/m^2)	Size (mm)	Density (no/m^2)	Biomass (mg/m^2)	Size (mm)	Density (no/m^2)	Biomass (mg/m^2)	Size (mm)	Density (no/m^2)	Biomass (mg/m^2)	Size (mm)	Density (no/m^2)	Biomass (mg/m^2)	Size (mm)	Density (no/m^2)	Biomass (mg/m^2)	Size (mm)	Density (no/m^2)	Biomass (mg/m^2)
1987	4	28,835	100	0.91	173	1	1.01	4,127	6	0.65	138,370	134	0.33	3,218	4	0.54	2,574	6	0.52	177,297	251
1988	4	22,360	77	0.91	0	0		3,185	5	0.69	106,462	104	0.33	962	2	0.71	1,228	3	0.53	134,197	191
1989	5	16,322	71	0.99	0	0		3,663	5	0.66	69,638	59	0.31	1,778	3	0.64	1,347	3	0.48	92,748	141
1990	7	15,378	60	0.95	7	0	0.90	9,987	16	0.68	155,051	134	0.31	3,392	5	0.61	4,944	9	0.47	188,759	224
1991	6	21,278	102	1.02	265	1	0.79	6,606	12	0.74	208,574	193	0.32	4,089	9	0.72	4,025	8	0.50	244,837	325
1992	7	23,468	104	0.99	485	1	0.88	4,807	8	0.68	106,832	108	0.33	5,513	13	0.74	3,306	6	0.45	144,411	240
1993	7	33,893	127	0.94	76	0	0.83	5,960	11	0.72	240,817	247	0.34	7,689	14	0.66	3,715	8	0.50	292,150	407
1994	8	23,713	66	0.85	1,844	7	0.98	10,231	17	0.69	257,749	256	0.33	9,621	18	0.66	7,271	13	0.48	310,429	377
1995	7	16,758	84	1.04	5,596	16	0.87	24,932	39	0.68	212,768	197	0.32	13,740	22	0.62	1,410	2	0.46	275,204	360
1996	5	42,112	223	1.06	191	0	0.49	11,614	19	0.69	350,806	378	0.34	16,072	44	0.78	2,909	5	0.47	423,704	670
1997	6	14,367	69	1.02	5,520	11	0.75	24,567	41	0.69	81,591	66	0.30	11,720	17	0.58	915	1	0.43	138,679	205
1998	4	15,672	62	0.96	1,088	5	1.05	2,070	3	0.67	169,971	144	0.31	10,881	14	0.56	5,441	8	0.42	205,123	236
1999	4	18,737	78	0.97	5,945	24	0.97	6,688	12	0.71	133,175	130	0.33	9,449	20	0.68	2,495	5	0.46	176,489	269
2000	5	57,643	180	0.88	8,121	44	1.09	10,743	16	0.66	114,297	126	0.35	5,042	9	0.64	1,408	2	0.46	116,722	188
2001	5	30,122	66	0.77	2,548	6	0.79	8,121	10	0.61	40,764	33	0.30	1,253	1	0.49	2,638	4	0.43	85,446	120
2002	4	8,174	21	0.82	1,009	3	0.92	6,380	7	0.56	38,256	36	0.32	2,935	3	0.51	557	1	0.41	57,311	71
2003	4	39,743	73	0.73	3,782	7	0.74	3,185	4	0.62	102,110	85	0.30	1,393	2	0.60	1,194	2	0.48	151,407	173
Avg.	5	25,210	92	0.93	2,156	7	0.87	8,639	14	0.67	148,661	143	0.32	6,397	12	0.63	2,787	5	0.47	189,113	262

Station 2		*Epischura*			*Diaptomus*			*Cyclops*			*Bosmina*			*Daphnia*			*Holopedium*			TOTALS	
Year	No. Samples	Density no/m^2	Biomass mg/m^2	Size mm	Density no/m^2	Biomass mg/m^2	Size mm	Density no/m^2	Biomass mg/m^2	Size mm	Density no/m^2	Biomass mg/m^2	Size mm	Density no/m^2	Biomass mg/m^2	Size mm	Density no/m^2	Biomass mg/m^2	Size mm	Density no/m^2	Biomass mg/m^2
1988	4	10,656	45	0.98	40	0	1.44	809	1	0.70	108,838	110	0.33	1,405	3	0.65	942	3	0.55	122,690	162
1989	5	10,306	35	0.90	0	0		1,261	2	0.66	48,235	40	0.30	420	1	0.63	553	1	0.46	60,775	79
1990	7	12,610	48	0.94	0	0		3,460	5	0.66	128,277	108	0.31	2,350	4	0.64	4,026	7	0.47	150,723	172
1991	6	19,285	80	0.97	1,274	4	0.89	4,277	8	0.74	154,341	132	0.31	3,347	6	0.65	5,083	10	0.49	187,607	240
1992	7	8,948	34	0.94	144	1	1.00	1,436	2	0.67	82,879	84	0.33	2,521	5	0.70	1,579	3	0.45	97,507	129
1993	7	19,033	70	0.93	773	1	0.69	3,882	5	0.62	175,106	157	0.32	2,570	5	0.67	3,988	7	0.47	205,352	245
1994	8	11,006	40	0.93	783	3	0.91	2,736	4	0.65	125,352	116	0.32	4,321	7	0.64	2,468	4	0.46	146,666	174
1995	7	12,193	44	0.92	1,168	4	0.94	9,054	11	0.61	111,525	98	0.31	8,902	12	0.58	1,152	1	0.4	143,994	170
1996	5	20,892	99	1.02	255	2	1.17	2,930	6	0.77	219,747	239	0.35	4,331	11	0.76	1,571	2	0.46	249,726	359
1997	6	13,677	57	0.97	3,468	7	0.75	3,822	5	0.64	86,060	63	0.29	9,652	13	0.56	924	1	0.41	117,601	146
Avg.	6	13,861	55	0.95	790	2	0.97	3,367	5	0.67	124,036	115	0.32	3,982	7	0.65	2,229	4	0.46	148,264	188